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Flexible Ships

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Abstract

The current global security environment is changing at a faster pace than ever before with higher levels of complexity and competitiveness, with a complex dynamic of possibilities. The U.S. Navy not only needs more platforms or ships, but it needs them with the ability to adapt to changes with new technologies and operational concepts. One such concept is that of flexibility in our fleet of ships. To successfully implement the Surface Navy's Flexible Ships concept, PEO-SHIPS requires a new methodology that assesses the total future value of various combinations of Flexible Ships' design features and how they will enable affordable warfighting relevance over the ship's full-service life. Examples of Flexible Ships design features include decoupling payloads from platforms, standardizing platform-to-payload interfaces, implementing allowance for rapid reconfiguration of onboard electronics and weapons systems, preplanning access routes for mission bays and mission decks, and allowing for sufficient growth margins for various distributed systems. This research analyzes the application of strategic Real Options Valuation methodology within the Integrated Risk Management process to assess the total future value of Flexible Ships design features and for use in the Future Surface Combatant Analysis of Alternatives. The current research has the explicit goal of proposing a reusable, extensible, adaptable, and comprehensive advanced analytical modeling process to help the U.S. Navy in quantifying, modeling, valuing, and optimizing a set of ship design options to create and value a business case for making strategic decisions under uncertainty.

Introduction

The current global security environment is changing at a faster pace than ever before with higher levels of complexity and competitiveness, with a complex dynamic of possibilities. Not only does the U.S. Navy need more platforms or ships, but it needs them with the ability to adapt to changes with new technologies and operational concepts. One such concept is that of flexibility in our fleet of ships.

In the Flexible Ships IPT Charter signed out by the nine Flag Officers/SESs last year, the IPT is tasked to "make recommendations to leadership for policy/process changes that will foster incorporation of flexible ships features into current and future ships."

The U.S. Navy is tasked with fulfilling its missions globally in environments with rapidly changing threats using an equally rapidly evolving technological base of platform, mission, electronic, and weapon systems. The challenge the U.S. Navy faces is to retain and maintain sufficient military relevance during wartime as well as peacetime, with the added goal of minimizing highly intrusive and costly modernization throughout a ship's service life by incorporating Modular Adaptable Ships (MAS) and Flexible and Adaptable Ship Options (FASO) in the ship design. Accomplishing this goal has the added benefit of allowing the Navy to affordably and quickly transform a ship's mission systems over its service life to maintain its required military capabilities (Doerry, 2012).

The operative term in FASO is *flexibility*. To have flexibility means to have the options to make midcourse corrections and changes as required, when uncertainties become resolved over the passage of time, actions, and events. In other words, the uncertainties of what future technologies may look like and the ever-changing complexity of global threats balanced with the need for the U.S. Navy to be responsive and persistent, and to maintain a fleet that provides leaders and decision-makers with credible and exercisable options, requires flexibility. When uncertainties become known, the correct course of action can be implemented, but only if the flexibilities exist. Therefore, by definition, having flexibility or options in place and ready to execute provides value as well as a lower overall cost of making major ship changes and alterations when the occasion calls for them.

Having a 355-ship navy is by itself insufficient regarding effectiveness. It is becoming more critical to consider what these platforms are capable of in terms of creating an effect and affecting desired outcomes, having flexibility to adapt to ever-changing threats, and possessing the ability to incorporate evolutionary technology upgrades as they become available. Current levels of technology are insufficient for maintaining maritime superiority. New operational concepts and technologies need to be consistently updated in our fleet. In most cases, timing is critical. We cannot wait until our adversaries have a new technology before testing and implementation begins on our end.

Flexibility and modularity provide the U.S. Navy with the options to execute various capabilities quickly. Future flexible ships can be designed such that they are modular with rapidly swappable components. New technologies (sensors, weapon systems, system upgrades) can be implemented rapidly at lower costs if the ship was designed with future flexibility and upgrades in mind. Flexibility is synonymous with *options*. That is, with flexible ships, leadership has the option, but not the obligation, to execute any of the available trigger points when conditions make it optimal to do so.

To understand the Flexible Ships concept, one has to first look at its basic principles and tenets. Sturtevant (2015) lists the five main tenets of flexible ships:

1. Decoupled payloads (capabilities) from platforms (ships)
2. Standard platform-to-payload interfaces—well-defined, common interfaces for distributed ship services that are prescribed and managed by the U.S. Navy
3. Rapid reconfiguration—specific C5I compartments that can be easily reconfigured with upgraded equipment or new systems
4. Preplanned access routes—used for the easy removal and replacement of interior equipment or systems
5. Sufficient service life allowance growth margins (space and weight for future capabilities, and provision for projected demand for distributed systems such as electric power, cooling, and network bandwidth)

This current research focuses on applying a series of analytical methodologies, such as Real Options Valuation (ROV), to support development of a business model or business case analysis that supports strategic decision-making in the context of uncertainty. This analysis identifies, models, values, and optimizes the various strategic real options identified for flexible ship designs. Currently, there is only a limited set of real-life applications of FASO/MAS in ship design, and they are classified; therefore, actual empirical data is not used in this research. In addition, because the objective of this research is to illustrate in detail the business case modeling process and analytical methodologies such that the method and process can be replicated and used in all future FASO/MAS design decisions, subject matter expert (SME) inputs, publicly available information, and a set of basic assumptions or rough order magnitude (ROM) estimates are used. The use of the ROM or SME inputs, while subjective in nature, in no way detracts from the analytical power, efficacy, or applicability of these methods, because the values they supply to the model parameters can be replaced with more objective values as they become available.

Literature Review

The concept of FASO is not new to the Navy. In fact, benefits of FASO/MAS concepts were detailed in the mid-1970s by Jolliff (1974), Simmons (1975), Drewry and Jons (1975), and others. Even as recently as 2015, the Naval Sea Systems Command's (NAVSEA's) Program Executive Office, Ships (PEO-SHIPS) put out a presentation on Flexible Ships, detailing its "Affordable Relevance over the Ship's Life Cycle" (Sturtevant, 2015). In it, the director of science and technology, Glen Sturtevant, noted that the main current and future challenges confronting the surface Navy include facing unknown but evolving global threats while managing an accelerated pace of technological changes, coupled with handling rising costs and declining budgets. The analysis found that ships currently cost too much to build and sustain, the ships (platforms) are too tightly coupled with their capabilities (payloads), and inflexible and fixed architectures of legacy ships limit growth and capability upgrades or result in lengthy and costly upgrades. The effects of these issues, of course, are compounded by ever-evolving, unknown global threats.

When the Freedom and Independence classes of American littoral combat ships (LCSs) were planned in the late 1990s, designers focused on swappable rapid reconfiguration of combat capabilities through interchangeable mission modules. Anti-submarine and surface warfare mission modules could be interchanged within hours in the presence of an evolving threat. Beyond the LCS's standard littoral combat and protection missions, these "plug-and-fight" mission modules provide significant combat flexibility within a single hull and cost savings in terms of having to maintain a smaller number of ships. In contrast to the traditional shipbuilding approach of cramming a wide-ranging set of bolted-in equipment into fixed installations, flexible ships can radically change the ships' capabilities, by swapping in a full breadth of equipment focused on a particular need (Berkok, Penney, & Kivinen, 2013).

Some examples of MAS and FASO that had been espoused in Navy research literature include decoupling of payloads from platforms, standardizing platform-to-payload interfaces, rapid reconfiguration, preplanned access routes, and sufficient service life allowance for growth (such as in Sturtevant, 2015; Doerry, 2012; Koenig, 2009; Koenig, Czapiewski, & Hootman, 2008; and others). These FASO approaches can be applied to a whole host of systems such as weapons, sensors, aircraft, unmanned vehicles, combat systems, C4I, flexible infrastructure, flexible mission bays and mission decks, vertical launch systems (VLSs) for various multiple missile types, future high-powered surface weapons (laser weapon systems and electromagnetic railguns), and modular payloads (e.g., anti-submarine warfare, special operations, mine warfare, intelligence gathering, close-in weapon systems, harpoon launchers, rigid hull inflatable boats, and gun systems).

More recently, Real Options theory has been recommended for evaluating the value of MAS technologies. Real Options theory proposes to apply financial options and analysis techniques to nonfinancial applications. Ship acquisition programs are characteristic of projects that benefit from investment options. MAS technologies provide those options. Real Options theory projects the value of being able to make decisions in the future when improved information is available to make a better decision. Gregor (2003), Koenig (2009), and Page (2011) provide good insights into the benefits and limitations of applying Real Options theory to naval ship acquisitions.

Flexible and Adaptable Ship Design

Seventy percent of the world is covered by water. To ensure freedom of navigation, economic independence, and national sovereignty, countries must maintain a highly efficient and technologically advanced fleet. With shrinking defense budgets, the current trend is to build fewer warships but maintain the same operational tempo. To continually meet the demands of a larger operational fleet, these new smaller fleets must be built on flexible and adaptable platforms with decoupled payloads that allow the vessel to accomplish a multitude of mission sets. This type of modular design and build "offers an opportunity for a ship to affordably transform its mission systems over its service life to maintain military relevance" (Doerry, 2012). The design characteristics that allow these fleets to flourish are Modular Adaptable Ships (MAS) and Flexible and Adaptable Ship Options (FASO; Mun & Housel, 2016). MAS- and FASO-incorporated designs provide an economical platform for a seagoing navy to build highly effective warships capable of performing various missions in a multitude of environments.

Flexible and adaptable ship designs are centered around a standard hull with modular mission payloads that offer a wide mission set, affordable scalability, reduced operational downtime, increased availability of the ship, and a reduced total number of mission modules for the fleet (Thorsteinson, 2013). For navies with limited budgets, having a flexible and modular platform allows a vessel to perform at times like a frigate and at other times like a corvette (Paris, Brussels, & Fiorenza, 2013). These new multi-mission vessels are already operational in blue-water fleets around the world operated by countries including Denmark, Germany, France, Italy, Australia, and the United States.

Modular build and design have been in use since the mid-20th century. During World War II, Henry Kaiser's shipyards were able to produce Liberty ships in minimal time due in part to the heavy use of modular construction, and the Germans constructed their Type 21 submarines with modular build principles (Abbott, Levine, & Vasilakos, 2008). Starting in 1979, the German shipyard Blohm & Voss began building modular corvettes and frigates for third-world navies using a modular concept known as MEKO. The MEKO concept has continually evolved with time producing the more mature MEKO A-100, A-200, and now A-400. In 1986, the Royal Danish Navy (RDN) began implementation of a modular concept called STANFLEX for a new class of patrol craft (Abbott et al., 2008) known as the Flyvefisken (SF 300) class. The specific use of modular mission payload within the SF 300s directly translated into the future design and development of the RDN Absalon support ships and Iver Huitfeldt class frigates. The French and Italians have worked together to design a flexible multi-mission frigate known as the FREMM class, while the Australian Royal Navy has the modular Anzac class of frigates and Hobart class of air-warfare destroyers (AWDs).

Cost reduction may come in the form of increases in timely switches between capabilities that may also affect procurement, maintenance, and operating costs. For instance, mission modules stored at forward hubs or onboard, while increasing ship costs, may reduce the number of trips to the home port significantly. Moreover, since modularity severs the jointness of various capabilities onboard the platform, a given module can be upgraded relatively independently of others (Berkok et al., 2013).

For many years, ships have been constructed in a modular fashion. That is, significant portions of the ships are built as modules, and the modules are then put together as a final assembly. But "modular capability focuses not on the overall construction of the ship but, rather, on the rapid plug-and-play installation of capabilities such as guns, missiles, unmanned vehicles, SONARs, special forces accommodations, etc." (MacKenzie & Tuteja, 2006). In addition, according to the authors, there are three key modular design types within the naval ship context:

- STANFLEX concept of the Royal Denmark Navy
- MEKO concept of Blohm + Voss GmbH
- Modular Platform Concept (MOPCO) of Abeking & Rasmussen (A&R)

Of the three design types, MEKO is most popular internationally. MEKO vessels are employed by Australia, Turkey, Greece, Germany, South Africa, and other countries. It is interesting to note that although MEKO naval ships are modular in design, there is little evidence that modularity is actually being used in the operation of these vessels. The main benefits of modularity and flexible ships include the following:

- Operational flexibility (i.e., the ability to reconfigure ship for various missions)
- Increased availability of the ship (i.e., reduced operational downtime)
- Reduced total number of mission modules for the fleet, resulting in cost savings

MEKO platforms are designed specifically for the varied deployment of standardized modules (weapons, electronics, and the ship's technical equipment) which are also connected with the power supply, the air-conditioning and ventilation system, and the data network, for example, via standardized interfaces. All the components needed to run a specific system are accommodated in a single module (MacKenzie &Tuteja, 2006).

Royal Danish Navy

The Royal Danish Navy (RDN) has been at the forefront of modular ship design since 1987 when the first of 14 Flyvefisken class or STANFLEX 300 (SF 300) multi-role vessels (MRVs) were commissioned to replace its fleet of 24 mission-specific ships (eight Fast Attack Craft [FAC], eight patrol boats, and eight mine countermeasure vessels) with a smaller number of multi-role vessels (MRVs; Pike, 2011). The design was based on a standard hull that used modular bays, four interchangeable mission containers, to change mission type through use of the Standard Flex (STANFLEX) concept. The ability to quickly and efficiently swap payload allowed these MRVs to serve the following mission sets: anti-air defense (AAW); anti-surface warfare (ASuW); anti-submarine warfare (ASW); electronic warfare (EW); mine countermeasures (MCM); patrol and surveillance; and pollution control (Pike, 2011). STANFLEX and modular payload allowed for containers to be pre-staged for mission flex while simultaneously reducing downtime for technological upgrades, which could be applied to the appropriate container as opposed to the ship itself. The Flyvefisken class was ultimately decommissioned in October 2010 ("Flyvefisken Class (SF 300), Denmark," n.d.), but the use of the STANFLEX concept played a fundamental role in the design and development of the larger follow-on modular designs seen in the Absalon class littoral support ships and Iver Huitfeldt class frigates.

To meet the rising need for a blue-water navy, the RDN commissioned two flexible support ships, HDMS Absalon in 2004 and HDMS Exbern Snare in 2005. Capitalizing on the success of the STANFLEX design and the use of payload modularity, the Absalon class features five STANFELX container wells located amidships on the weapons deck (Lundquist, 2012; Pike, 2016). Under the various configurations, the Absalon class could be "equipped for naval warfare, land attack, strategic sealift missions, emergency disaster relief or as a hospital ship" ("Absalon," n.d.). The Absalon class demonstrated that modularity could be applied to larger combatant ships and was not localized to smaller littoral ships. Continuing to capitalize on the growing success of its modular techniques, the RDN moved forward with designing and building a flexible and adaptable frigate fleet.

German Navy

At the forefront of modular design for the German Navy is Blohm + Voss. The design concept known as Mehrzweck-Kombination (MEKO), which translates as "multi-purpose combination," has been utilized in ship construction and design since the 1970s. MEKO designs rely heavily on modularity that increases the speed at which the ship can be built and facilitates faster upgrades and refits. The success of the MEKO class can be seen in 13 navies worldwide in various corvettes and frigates (Kamerman, 2015). The modular mission payloads in 20-foot standardized ISO containers create adaptability and flexibility and allow navies to rapidly reconfigure mission type based on operational needs. Modules can be rotated for upgrades and maintenance or passed between ships, which reduces the number of overall payloads required for the fleet. This simple reduction results in significant cost savings in procurement and maintenance over the life cycle of the ship ("ThyssenKrupp," n.d.). The MEKO class is the backbone for the new German frigate class, the Baden-Württemberg (F125).

The German Navy will acquire four Baden-Württemberg class frigates to replace the eight frigates in the Bremen class (F122) commissioned in the 1980s. The Baden-Württemberg frigate design incorporates enhanced survivability capabilities that include floating, moving, and fighting after sustaining damage; embarking and deploying special forces; and maintaining prolonged periods at sea with little maintenance. It also incorporates modular mission capabilities (Kamerman, 2015). The design flexibility of the F125 will double the availability of the current German frigate fleet (Kamerman, 2015) while simultaneously reducing overhead.

American Navy

Littoral Combat Ship

As the U.S. Navy began to phase out its fleet of 51 Oliver Hazard Perry class frigates, its leadership began to look for a high-tech platform that could be used as a replacement (Osborn, 2015). The end result was the Littoral Combat Ship (LCS) in two variants: the trimaran-hull Independence class and the mono-hull Freedom class. The concept of the LCS was a highly flexible and adaptable ship that would allow the U.S. Navy to operate in littoral areas with a focus on maritime security and anti-piracy (Stashwick, 2016). "The ships were designed to be high-speed (over 40 knots) and highly maneuverable, with the ability to swap out modules to provide mission-specific capabilities like anti-submarine, anti-surface, and mine-clearing" (Stashwick, 2016). Both variants of the LCS included a mission bay in the design to house elements of mission packages. Within the LCS class, "mission packages are composed of mission modules, aircraft, and crew detachments to support the mission modules and aircraft" (Doerry, 2012).

The Freedom class is built on a steel monohull and is capable of incorporating three mission packages: anti-submarine warfare (ASW), anti-surface warfare (ASuW), and mine countermeasures (MCM). The flexible design "incorporates a large reconfigurable seaframe to allow rapidly interchangeable mission modules, a flight deck with integrated helicopter launch, recovery, and handling systems and the capability to launch and recover maritime vehicles (manned and unmanned) from the stern side" ("Freedom," 2016). The low total gross weight allows the LCS class to obtain speeds greater than 40 knots. The design trade-off for speed was sustained battle damage capability. Where other surface combatants could withstand and potentially recover from sustained-high intensity conflict, the Freedom class would likely result in abandonment of the vessel in the same type of conflict (Stashwick, 2016).

The Independence class of littoral combat ships was designed on an aluminum trimaran hull form based on a commercial ferry design used by the Norwegian company Fred Olsen ("Independence," 2016). As with the Freedom class, the Independence is capable of performing three mission packages: anti-submarine warfare (ASW), anti-surface warfare (ASuW), and mine countermeasures (MCM). The flexible design incorporates a "reconfigurable seaframe to allow rapidly interchangeable mission modules" that include three modular weapon stations ("Independence," 2016).

Small Surface Combatant

The U.S. Navy originally contracted 52 littoral combat ships, but in January 2014, Secretary of Defense Chuck Hagel "instructed the Navy that there would be no new contracts awarded for LCS production beyond 32 ships" (Osborn, 2015). In place of the remaining 20 littoral combat ships, the Navy was to build a Small Surface Combatant ship. On January 15, 2015, Secretary of the Navy Mabus stated that a new class of ship was required to have frigate-like capabilities and thus would change the designation of the last 20 ships from LCS to FF (Osborn, 2015).

The new frigate will capitalize on the two existing hull variants used in the Freedom and Independence classes (Eckstein, 2015). Speaking at an American Society for Naval Engineers event, CAPT Dan Brintzinghoffer stated that the new frigate would take the basic LCS design but differ in that it "will be more lethal, more survivable, and will be able to conduct surface warfare and anti-submarine warfare simultaneously, whereas the LCS had to choose only one mission package to work with at any given time" (Eckstein, 2015). The new class of frigates will trade the high-speed capability of the LCS class in order to accommodate the additional weight created by the heavier armor for increased survivability (Eckstein, 2015). To make the new frigate class cost-efficient, CAPT Brintzinghoffer stated that commonality will be required across both variants, and it will likely need to share some modular aspects with the LCS class or some commonalities with other classes of surface combatants (Eckstein, 2015). This new class of frigates represents an opportunity for the U.S. Navy to build on an existing hull, capitalizing on cost savings in the early design process, and incorporate more advanced flexible and adaptable modules in the payload design. A proven example of a flexible and adaptable frigate with modular payload with similar tonnage is the MEKO A-200 class frigate. The MEKO class family is designed for sustained battle damage and could provide guidance for enhanced survivability options for this new class of American frigates.

FASO/MAS at PEO-SHIPS: Guided Missile Destroyers

DDG 51 FLIGHT III

The Arleigh Burke class of Guided Missile Destroyers (DDG) is the U.S. Navy's first class of destroyer built around the Aegis Combat System and the SPY-1D multi-function passive electronically scanned array radar. The class is named for Admiral Arleigh Burke, the most famous American destroyer officer of World War II and later chief of naval operations. The class leader, USS *Arleigh Burke*, was commissioned during Admiral Burke's lifetime (Office of the Director, Operational Test and Evaluation [DOT&E], 2013).

The DDG class ships were designed as multi-mission destroyers to fit the AAW role with their powerful Aegis radar and surface-to-air missiles; the anti-submarine warfare (ASW) role with their towed sonar array, anti-submarine rockets, and ASW helicopter; the anti-surface warfare (ASuW) role with their Harpoon missile launcher; and the strategic land strike role with their Tomahawk missiles. With upgrades to AN/SPY-1 phased radar systems and their associated missile payloads, as part of the Aegis Ballistic Missile Defense System, members of this class have also begun to demonstrate some promise as mobile anti-ballistic missile and anti-satellite weaponry platforms. Some versions of the class no longer have the towed sonar or Harpoon missile launcher (DOT&E, 2013).

The DDG 51 class destroyers have been designed to support carrier strike groups, surface action groups, amphibious groups, and replenishment groups. They perform primarily AAW with secondary land attack, ASW, and ASuW capabilities. The MK41 vertical launch system has expanded the role of the destroyers in strike warfare, as well as their overall performance. The U.S. Navy will use the DDG 51 Flight III Destroyer equipped with the Aegis modernization program and AMDR to provide joint battlespace threat awareness and defense capability to counter current and future threats in support of joint forces ashore and afloat.

Step 1: Identification of FASO/MAS Options

The following provides two high-level examples of identifying and framing strategic flexibility options in the DDG 51 and DDG1000 environments. These are only notional examples with rough order magnitude values to illustrate the options framing approach.

This real options example illustrates the implications of the standard LM2500 GE Marine Gas Turbines for DDG 51 FLT III ships versus the Rolls-Royce MT30 Marine Gas Turbine Engines for the Zumwalt DDG 1000, where the latter can satisfy large power requirements in warships. The LM2500 provides 105,000 shaft hp for a four-engine plant. In comparison, the MT30 can generate upwards of 35.4 MW, and its auxiliary RR4500 Rolls-Royce turbine generators can produce an added 3.8 MW, and each DDG1000 carries two MT30s and two RR4500s. This means that the combined energy output from the Zumwalt can fulfill the electricity demands in a small- to medium-sized city. In contrast, two LM2500 gas turbines can only produce a total of 95.2 kW, which is approximately 0.12% or 1/825 of the power the Zumwalt can produce. Manufacturer specifications indicate that the LM2500 has an associated Cost/kW of energy of $0.34 and the MT30 Cost/kW is $0.37. In addition, the MT30 prevents warships from running off balance when an engine cannot be restarted until it has cooled down, as is the case in the LM2500.

Figure 1 illustrates a real options strategy tree with four mutually exclusive paths. Additional strategies and pathways can be similarly created, but these initial strategies are sufficient to illustrate the options framing approach. Path 1 shows the As-Is strategy, where no additional higher capacity power plant is used; that is, only two standard LM2500 units are deployed, maintain zero design margins for growth, and only the requirements for the current ship configuration are designed and built. Medium and large upgrades will require major ship alterations, with high cost and delayed schedule. Path 2 implements the two required LM2500 units with additional and sufficient growth margins for one MT30 power plant but currently only with a smaller power plant incorporated into the design. Sufficient area or modularity is available where parts of the machinery can be removed and replaced with the higher energy production unit if needed. Upfront cost is reduced, while future cost and schedule delays are also reduced. Path 3 is to have two prebuilt MT30s and RR4500s initially. While providing the fastest implementation pathway, the cost is higher in the beginning, but the total cost is lower if, indeed, higher energy weapons will be implemented. Path 4 is an option to switch whereby one LM2500 is built with one MT30 unit. Depending on conditions, either the LM2500 or MT30 will be used (switched between units). When higher-powered future weapons are required, such as electromagnetic railguns (EM Rail Guns) or high-intensity lasers (HI Lasers) as well as other similarly futuristic weapons and systems, the MT30 can be turned on.

Having a warship flexibility with two LM2500s (As-Is base case) allows the Navy a savings of $31.76 million by deferring the option of the other two additional LM2500s. Therefore, by having a flexible ship, the Navy can invest later in one LM2500 and attach another MT30 (preventing any engine off-balance effects when the engines cannot be restarted due to excessive heat) and can save $34.58 million. The usage of options to defer/invest that combine gas turbine specifications allows the Navy to prevent high sunk costs, properly adjusting the true kW requirements, and allows different combinations of propulsion and energy plants. This analysis can be further extended into any direction as needed based on ship designs and Navy requirements.

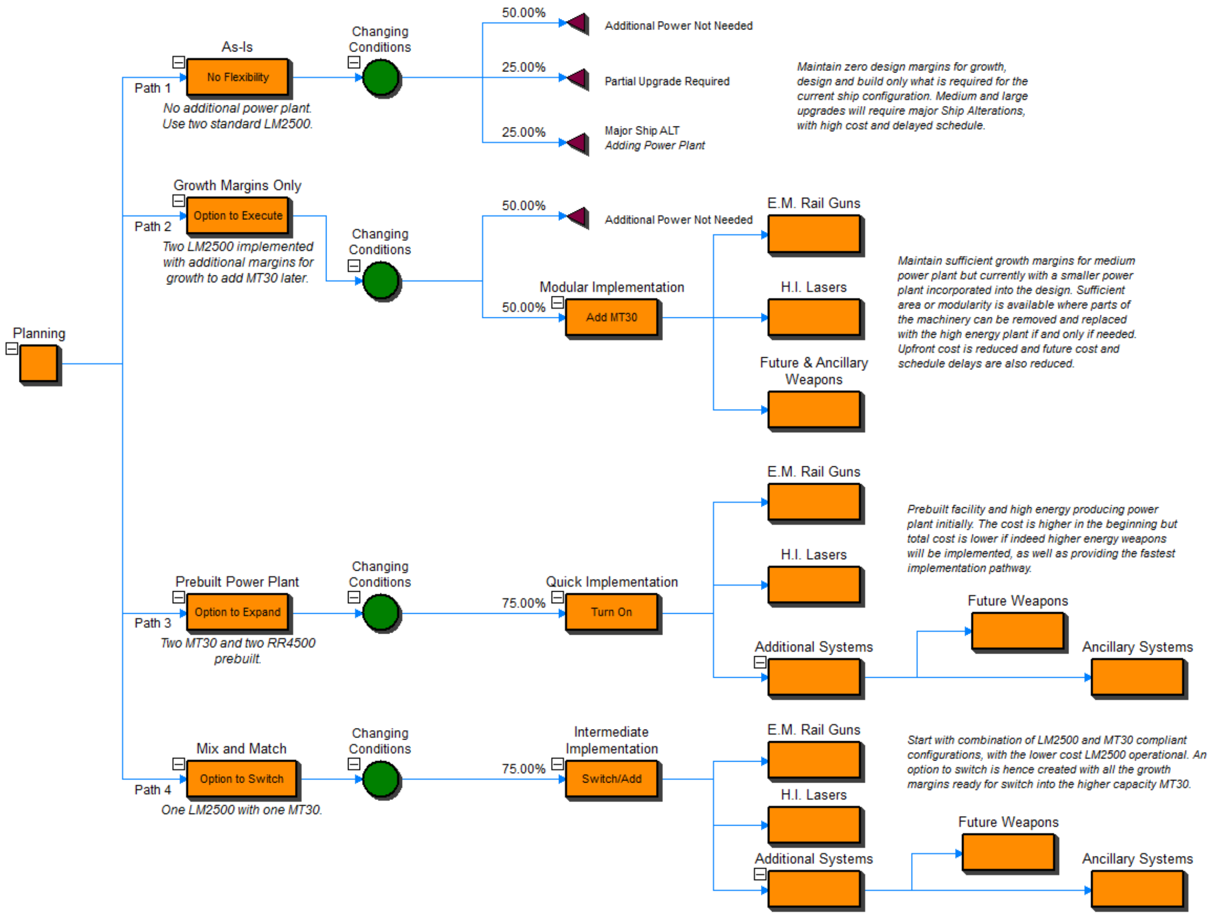


Figure 1. Options Framing on Power Generation

Vertical Launch Systems

Another concern of the DoD is the large capital investment required in vertical launch systems (VLSs) in U.S. Navy ships. VLSs need to be developed and integrated per Navy requirements, which are constrained by rapid technological change and high uncertainties in costs. The usage of strategic real options aims to assess whether the Navy can *keep the option open* to defer the large investments to help avoid high sunk costs and quick technological obsolescence or should pre-invest in a new VLS. Consequently, flexibility and uncertainty create the right environment to model VLSs using a real options framework. According to DDG 51 (Flight II and Flight III) specifications, the estimated cost of a single VLS is approximately $228 million. The most expensive subarea is the MK41 subsystem (DDG 51 contains two MK41s). This current example is developed based on the assumptions of a rapid technological obsolescence, high integration costs, time delays, and reduced capability, which can all jeopardize Navy investments in the VLS.

In addition, using a real options framework to possibly defer the implementation of MK41 would allow ship designers and engineers to incorporate modernization and upgrade margins in the VLS within the ship design early on, and to defer the exact configuration of the VLS until a future date when uncertainties on capability requirements are resolved over the passage of time, action, and events. These capability requirements include integration, upgrades, changes, new technology, new requirements, and updated military warfighter needs. Also, we can evaluate the option to invest in the second or third MK41 as situational needs arise. Figure 2 shows two simple option paths, in which the first path indicates immediate execution, where two MK1s are implemented immediately, not knowing if both are actually needed, as opposed to the second strategic path, where the VLS is designed so that either two MK1s can be implemented or only one. Therefore, one MK1 can be first inserted and the second added on later only when required, where the VLS has design growth margins to adapt to slightly different technological configurations. The question, of course, is which strategic pathway makes most sense, as computed using strategic real options value.

When the flexibility value is added into the mix, the expected total cost is reduced from $110.10 million to $98.51 million. Finally, wartime scenarios can be incorporated into the analysis whereby if there is a higher probability of conflict where the VLS is required, the value to keep open the option to defer is reduced and the Navy is better off executing the option immediately and having the required VLS in place.

The project with flexibility is $118.22 million (flexible VLS warship open to integrate another MK41 in the future as and when needed) against $228.34 million (base case DDG 51 with no flexibility options, where the VLS is already built in). The Navy can save or delay the usage of $110.10 million by holding on to the option of deferring the second MK41. In addition, in the near future, the cost to implement the second MK41 can be reduced due to a flatter learning curve, economies of scale, and the specific technology becoming more readily available, less complex, and easier to implement, or it can be more expensive because the technology experiences new updates, higher performance, and greater efficiency. If cost volatility is the main variable for the Navy, we contrast deferring the second MK41 against the base case. It means that we compare the VLS system with no flexibility ($228.32 million) against the cost changes in the second MK41 (assuming Navy engineers develop a plug-and-play structure to integrate the next MK41 quickly).

This assumption can be relaxed using cost and schedule modeling and Monte Carlo simulation methods. In terms of the options valuation, the option to defer for the Navy follows cost comparisons. In other words, it reduces the cost exposure for the second MK41 from $110.10 million to an expected cost of $69.89 million. In addition, decision-makers observe in the options strategy tree and decision tree where they can keep the option to defer *open* and under what conditions the Navy should execute and invest in the second MK41. One likely extension is where the decision-maker can introduce probabilities or expectations of Navy actions (new missions and new requirements) or events (wartime, peacetime). This affects the flexibility of the second MK41 by constraining the option's flexibility to defer. For instance, if the Navy has strong expectations of requiring the second MK1 (wartime probability is higher than 30%), it reduces the value of the option to defer and accelerates the availability and execution of the second MK41 option earlier. In peacetime, the Navy has more flexibility in terms of how it implements or assesses its real options to wait and defer.

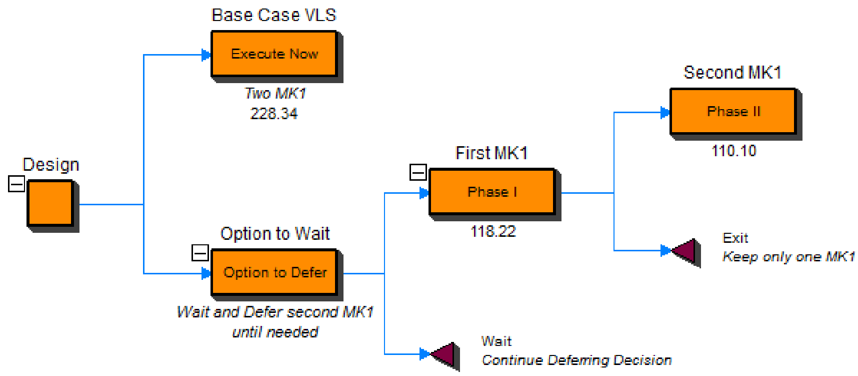


Figure 2. Options Framing on Vertical Launch Systems

Step 2: Cost Analysis and Data Gathering

Once the various FASO/MASO options are framed and modeled, as shown in the previous step, the modeling process continues with additional data gathering activities. Figure 3 shows some examples of shadow revenues (i.e., cost savings from lowered cost of future upgrades and technology insertions, costs mitigated by reducing the need for alternative equipment and lower spare parts, and other costs deferred by reducing the need for maintenance and operating costs) or cost savings, additional direct and indirect costs of implementing the new option, and capital requirements.

Step 3: Financial Modeling

The *Discounted Cash Flow* section, shown in Figure 3, is at the heart of the input assumptions for the analysis. Analysts would enter their input assumptions—such as starting and ending years of the analysis, the discount rate to use, and the marginal tax rate—and set up the project economics model (adding or deleting rows in each subcategory of the financial model). Additional time-series inputs are entered in the data grid as required, while some elements of this grid are intermediate computed values.

Analysts can also identify and create the various options and compute the economic and financial results, such as net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR), profitability index (PI), return on investment (ROI), payback period (PP), and discounted payback period (DPP). This is shown in Figures 3 and 4, complete with various charts, cash flow ratios and models, intermediate calculations, and comparisons of the options within a portfolio view, as illustrated in the figure. As a side note, the term *Option* is used to represent a generic analysis option, where each project can be a different asset, project, acquisition, investment, research and development, or simply variations of the same investment (e.g., different financing methods when acquiring the same firm, different market conditions and outcomes, or different scenarios or implementation paths). Therefore, the more flexible terminology of *Project* is adopted instead.

Figure 5 illustrates the *Economic Results* of each project. This figure shows the results from the chosen project and returns the NPV, IRR, MIRR, PI, ROI, PP, and DPP. These computed results are based on the analyst's selection of the discounting convention, if there is a constant terminal growth rate, and the cash flow to use (e.g., net cash flow versus net income or operating cash flow). An *NPV Profile* table and chart are also provided in the figure, where different discount rates and their respective NPV results are shown and charted. The *Economic Results* shown are for each individual project, whereas the *Portfolio Analysis* (see Figure 5) compares the economic results of all projects at once. The *Terminal Value Annualized Growth Rate* is applied to the last year's cash flow to account for a perpetual constant growth rate cash flow model, and these future cash flows, depending on the cash flow type chosen, are discounted back to the base year and added to the NPV to arrive at the perpetual valuation.

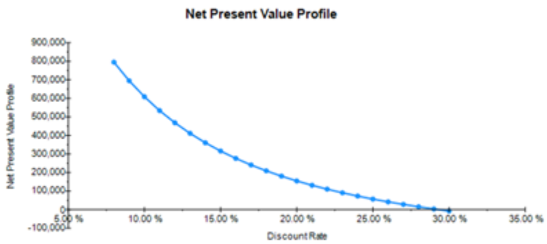
Static Portfolio Analysis and Comparisons of Multiple Projects

Figure 5 illustrates the *Portfolio Analysis* of multiple projects. This Portfolio Analysis returns the computed economic and financial indicators such as NPV, IRR, MIRR, PI, ROI, PP, and DPP for all the projects combined into a portfolio view (these results can be stand-alone with no base case or computed as incremental values above and beyond the chosen base case). The *Economic Results* show the individual project's economic and financial indicators, whereas this Level 2 *Portfolio Analysis* view shows the results of all projects' indicators and compares them side by side. There are also two charts available for comparing these individual projects' results. The *Portfolio Analysis* is used to obtain a side-by-side comparison of all the main economic and financial indicators of all the projects at once. For instance, analysts can compare all the NPVs from each project in a single results grid. The bubble chart on the left provides a visual representation of up to three chosen variables at once (e.g., the *y*-axis shows the IRR, the *x*-axis represents the NPV, and the size of the bubble may represent the capital investment; in such a situation, one would prefer a smaller bubble that is in the top right quadrant of the chart). These charts have associated icons that can be used to modify their settings (chart type, color, legend, etc.).

Year	2016	2017	2018	2019	2020	2021	2022	2023	...	2041	2042	2043
Revenues	$1,742.51	$11,737.14	$225,850.13	$225,850.13	$225,850.13	$225,850.13	$225,850.13	$225,850.13	...	$235,437.44	$235,437.44	$235,437.44
Cost Savings (Future Upgrades and Insertion)	$1,132.63	$7,629.14	$146,802.58	$146,802.58	$146,802.58	$146,802.58	$146,802.58	$146,802.58	...	$153,034.34	$153,034.34	$153,034.34
Cost Mitigated (Alternative Equipment)	$522.75	$3,521.14	$67,755.04	$67,755.04	$67,755.04	$67,755.04	$67,755.04	$67,755.04	...	$70,631.23	$70,631.23	$70,631.23
Cost Deferred (Maintenance and Operations)	$87.13	$586.86	$11,292.51	$11,292.51	$11,292.51	$11,292.51	$11,292.51	$11,292.51	...	$11,771.87	$11,771.87	$11,771.87
Direct Costs	$1,141.09	$1,141.09	$26,392.75	$26,392.75	$26,392.75	$26,456.81	$27,888.82	$27,888.82	...	$32,021.41	$32,021.41	$32,021.41
Direct Expenses	$1,110.26	$1,110.26	$24,896.68	$24,896.68	$24,896.68	$24,896.68	$24,896.68	$24,896.68	...	$25,961.75	$25,961.75	$25,961.75
Operational Costs	$18.50	$18.50	$414.95	$414.95	$414.95	$453.38	$829.89	$829.89	...	$1,730.79	$1,730.79	$1,730.79
Maintenance	$12.33	$12.33	$25.62	$25.62	$25.62	$51.25	$51.25	$51.25	...	$106.87	$106.87	$106.87
Direct Expenses	$0.00	$0.00	$1,055.50	$1,055.50	$1,055.50	$1,055.50	$2,111.00	$2,111.00	...	$4,222.00	$4,222.00	$4,222.00
Gross Profit (Operating Income)	$601.42	$10,596.05	$199,457.38	$199,457.38	$199,457.38	$199,393.32	$197,961.31	$197,961.31	...	$203,416.03	$203,416.03	$203,416.03
Indirect Expenses (General & Administrative)	$799.42	$3,073.28	$9,212.61	$9,212.61	$9,212.61	$9,212.61	$9,212.61	$10,877.49	...	$12,259.92	$9,465.41	$9,465.41
Training and Administrative	$0.00	$31.00	$703.00	$703.00	$703.00	$703.00	$703.00	$703.00	...	$733.00	$733.00	$733.00
Contracts and Bidding	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
Operations	$0.00	$0.00	$1,248.07	$1,248.07	$1,248.07	$1,248.07	$1,248.07	$1,248.07	...	$1,248.07	$1,248.07	$1,248.07
Maintenance	$799.42	$2,997.82	$4,758.48	$4,758.48	$4,758.48	$4,758.48	$4,758.48	$6,423.36	...	$7,733.14	$4,938.63	$4,938.63
Parts and Service	$0.00	$0.00	$1,506.00	$1,506.00	$1,506.00	$1,506.00	$1,506.00	$1,506.00	...	$1,506.00	$1,506.00	$1,506.00
Miscellaneous	$0.00	$44.46	$997.06	$997.06	$997.06	$997.06	$997.06	$997.06	...	$1,039.71	$1,039.71	$1,039.71
EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization	($198.00)	$7,522.77	$190,244.77	$190,244.77	$190,244.77	$190,180.71	$188,748.70	$187,083.82	...	$191,156.11	$193,950.62	$193,950.62
Depreciation	$0.00	$9,874.00	$39,827.00	$39,074.00	$38,161.00	$37,206.00	$36,172.00	$35,223.00	...	$24,502.00	$23,977.00	$23,444.00
Amortization	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
EBIT: Earnings Before Interest and Taxes	($198.00)	($2,351.23)	$150,417.77	$151,170.77	$152,083.77	$152,974.71	$152,576.70	$151,860.82	...	$166,654.11	$169,973.62	$170,506.62
Interest	$0.00	$6,779.32	$25,892.66	$22,767.15	$19,224.35	$15,842.53	$13,062.00	$12,303.79	...	$653.99	$666.90	$667.48
EBT: Earnings Before Taxes	($198.00)	($9,130.55)	$124,525.11	$128,403.62	$132,859.42	$137,132.18	$139,514.70	$139,557.03	...	$166,000.12	$169,306.72	$169,839.14
Corporate Taxes	($56.43)	($2,602.21)	$35,489.66	$36,595.03	$37,864.93	$39,082.67	$39,761.69	$39,773.75	...	$47,310.03	$48,252.42	$48,404.15
NET INCOME	($141.57)	($6,528.34)	$89,035.45	$91,808.59	$94,994.49	$98,049.51	$99,753.01	$99,783.28	...	$118,690.09	$121,054.30	$121,434.99
Total Noncash Expense Items	$0.00	$9,874.00	$39,827.00	$39,074.00	$38,161.00	$37,206.00	$36,172.00	$35,223.00	...	$24,502.00	$23,977.00	$23,444.00
Change in Net Working Capital	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
Capital Expenditures	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
Other Noncash Expenses	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
Total Gross Invested Operating Capital	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
CAPITAL INVESTMENTS	$250,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	...	$0.00	$0.00	$0.00
NET OPERATING PROFIT AFTER TAXES (NOPAT)	($141.57)	($1,681.13)	$107,548.71	$108,087.10	$108,739.90	$109,376.92	$109,092.34	$108,580.49	...	$119,157.69	$121,531.14	$121,912.23
NET CASH FLOW (NCF)	($141.57)	$3,345.66	$128,862.45	$130,882.59	$133,155.49	$135,255.51	$135,925.01	$135,006.28	...	$143,192.09	$145,031.30	$144,878.99
OPERATING CASH FLOW (OCF)	($141.57)	$8,192.87	$147,375.71	$147,161.10	$146,900.90	$146,582.92	$145,264.34	$143,803.49	...	$143,659.69	$145,508.14	$145,356.23
FREE CASH FLOW (FCF)	($141.57)	$8,192.87	$147,375.71	$147,161.10	$146,900.90	$146,582.92	$145,264.34	$143,803.49	...	$143,659.69	$145,508.14	$145,356.23

Figure 3. Financial Economic Cost Savings and Aversion Cash Flow Model

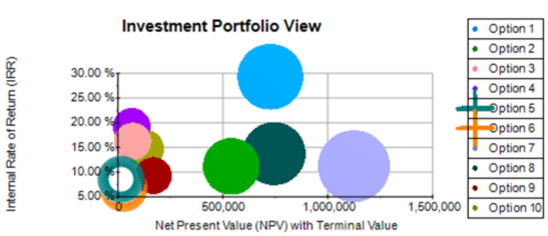
ECONOMIC INDICATORS	RESULTS
Net Present Value (NPV)	$608,388.34
Net Present Value (NPV) with Terminal Value	$726,488.77
Internal Rate of Return (IRR)	29.31%
Modified Internal Rate of Return (MIRR)	15.07%
Profitability Index (PI)	3.43
Return on Investment (ROI)	243.36%
Payback Period (PP)	3.80
Discounted Payback Period (DPP)	4.80



NPV PROFILE	
DISCOUNT %	NPV
8.00%	$794,590.13
9.00%	$694,674.49
10.00%	$608,388.34
11.00%	$533,487.10
12.00%	$468,141.66
13.00%	$410,854.85
14.00%	$360,395.93
15.00%	$315,748.74
16.00%	$276,070.74
17.00%	$240,660.35
18.00%	$208,930.96
19.00%	$180,389.99
20.00%	$154,622.20
21.00%	$131,276.09
22.00%	$110,052.97
23.00%	$90,698.01
24.00%	$72,993.02
25.00%	$56,750.42
26.00%	$41,808.40
27.00%	$28,026.89
28.00%	$15,284.18
29.00%	$3,474.16
30.00%	($7,495.93)

Figure 4. Financial and Economic Results

Economic Results	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
Net Present Value (NPV)	$608,388.34	$427,132.76	$40,765.22	$41,613.74	($10,610.44)	($23,774.85)	$728,339.38	$554,258.99	$31,837.41	$46,377.25
Net Present Value (NPV) with Terminal Value	72648877.00%	54046710.00%	7033594.00%	6615455.00%	1525722.00%	2718633.00%	112457959.00%	74402419.00%	16876439.00%	12973950.00%
Internal Rate of Return (IRR)	29.31%	11.17%	16.21%	19.21%	8.55%	6.76%	11.20%	13.74%	9.29%	14.77%
Modified Internal Rate of Return (MIRR)	0.15	0.10	0.12	0.13	0.09	0.08	0.10	0.11	0.07	0.10
Profitability Index (PI)	343.00%	114.00%	137.00%	154.00%	90.00%	86.00%	109.00%	129.00%	134.00%	176.00%
Return on Investment (ROI)	2.43	0.14	0.37	0.54	-0.10	-0.14	0.09	0.29	0.34	0.76
Payback Period (PP)	3.80	10.82	6.38	5.45	10.32	9.78	9.98	7.87	9.19	7.30
Discounted Payback Period (DPP)	$4.80	$22.81	$9.80	$7.84			$22.35	$13.79	$12.18	$9.21
Show on Charts										



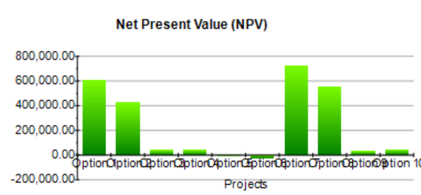


Figure 5. Static Portfolio Analysis

Step 4: Tornado and Sensitivity Analytics

Figure 6 illustrates the *Applied Analytics* results, which allows analysts to run *Tornado Analysis* and *Scenario Analysis* on any one of the projects previously modeled—the analytics cover all the various projects and options. We can, therefore, run tornado or scenario analyses on any one of the projects or options. Tornado analysis is a static sensitivity analysis of the selected model's output to each input assumption, performed one at a time, and ranked from most impactful to least impactful. We can start the analysis by first choosing the output variable to test.

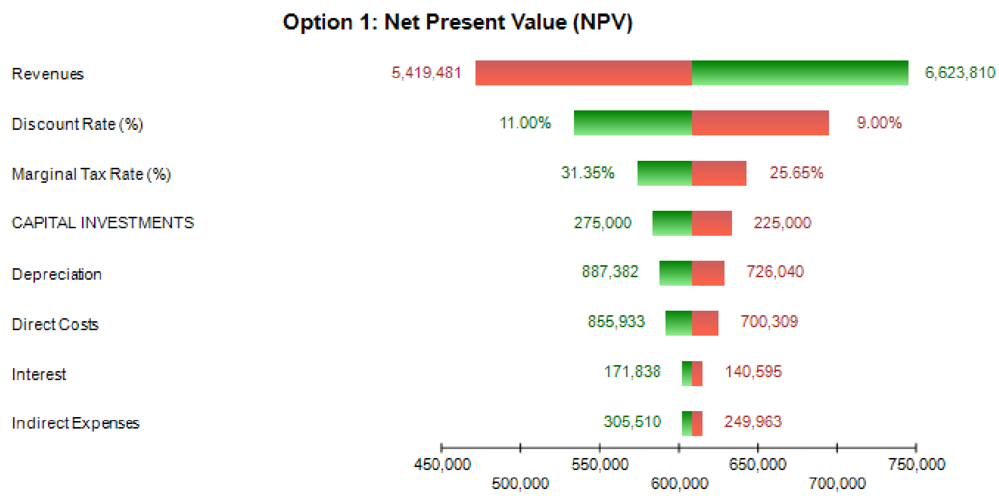


Figure 6. Applied Analytics—Tornado Analysis

We used the default sensitivity settings of ±10% on each input assumption to test and decide how many input variables to chart (large models with many inputs may generate unsightly and less useful charts, whereas showing just the top variables reveals more information through a more elegant chart). Analysts can also choose to run the input assumptions as unique inputs, group them as a line item (all individual inputs on a single line item are assumed to be one variable), or run as variable groups (e.g., all line items under Revenue will be assumed to be a single variable). Analysts will need to remember to click Update to run the analysis if they make any changes to any of the settings. The sensitivity run was based on the input assumptions as unique inputs, but the inputs can also be grouped as a line item (all individual inputs on a single line item are assumed to be one variable), or the analysis can be run as variable groups (e.g., all line items under Revenue will be assumed to be a single variable). The following summarizes the tornado analysis chart's main characteristics:

- Each horizontal bar indicates a unique input assumption that constitutes a precedent to the selected output variable.
- The *x*-axis represents the values of the selected output variable. The wider the bar chart, the greater the impact/swing the input assumption has on the output.
- A green bar on the right indicates that the input assumption has a positive effect on the selected output (conversely, a red bar on the right indicates a negative effect).
- Each of the precedent or input assumptions that directly affect the NPV with Terminal Value is tested ±10% by default (this setting can be changed); the top 10 variables are shown on the chart by default (this setting can be changed), with a 2-decimal precision setting; and each unique input is tested individually.
- The default sensitivity is globally ±10% of each input variable, but each of these inputs can be individually modified in the data grid. Note that a larger percentage variation will test for nonlinear effects as well.

- The model's granularity can be set (e.g., Variable Groups look at an entire variable group, such as all revenues, and will be modified at once; Line Items change the entire row for multiple years at once; and Individual Unique Inputs look at modifying each input cell).

Figure 7 illustrates the *Scenario Analysis* results, where the scenario analysis can be easily performed through a two-step process: Identify the model input settings and run the model to obtain scenario output tables. In the *Scenario Input settings*, analysts start by selecting the output variable they wish to test from the droplist. Then, based on the selection, the precedents of the output will be listed under two categories (*Line Item*, which will change all input assumptions in the entire line item in the model simultaneously, and *Single Item*, which will change individual input assumption items). Analysts select one or two checkboxes at a time, along with the inputs they wish to run scenarios on, and enter the plus/minus percentage and the number of steps between these two values to test. Analysts can also add color coding of sweetspots or hotspots in the scenario analysis (values falling within different ranges have unique colors). Analysts can create multiple scenarios and *Save As* each one (enter a name and model notes for each saved scenario).

Scenario analysis results can sometimes be used as heat maps to identify the combinations of input parameter conditions whereby the calculated outputs will be above or below certain thresholds. A visual heat map can be created by adding color thresholds in the scenario results table:

- Create and run scenario analysis on either one or two input variables at once.
- Scenario settings can be saved for future retrieval, which means analysts can modify any input assumptions in the options models and come back to rerun the saved scenarios.
- Increase/decrease decimals in the scenario results tables, as well as change colors in the tables for easier visual interpretation (especially when trying to identify scenario combinations, or so-called sweetspots and hotspots).
- Additional input variables are available by scrolling down the form.
- Line items can be changed using ±X%, where all inputs in the line are changed multiple times within this specific range all at once. Individual items can be changed ±Y units, where each input is changed multiple times within this specific range.
- Sweetspots and hotspots refer to specific combinations of two input variables that will drive the output up or down. For instance, suppose investments are below a certain threshold and revenues are above a certain barrier. The NPV will then be in excess of the expected budget (the sweetspots). Or if investments are above a certain value, NPV will turn negative if revenues fall below a certain threshold (the hotspots).

	20.00%	21.00%	22.00%	23.00%	24.00%	25.00%	26.00%	27.00%	28.00%	29.00%	30.00%	31.00%	32.00%	33.00%	34.00%	35.00%	36.00%	37.00%	38.00%
3,718,366.00	132,576.00	110,413.00	90,269.00	71,903.00	55,105.00	39,697.00	25,526.00	12,458.00	376.90	-10,818.00	-21,215.00	-30,891.00	-39,916.00	-48,348.00	-56,241.00	-63,642.00	-70,595.00	-77,135.00	-83,297.00
3,737,936.00	134,780.00	112,499.00	92,248.00	73,782.00	56,894.00	41,403.00	27,154.00	14,015.00	1,867.60	-9,388.80	-19,843.00	-29,573.00	-38,647.00	-47,126.00	-55,063.00	-62,507.00	-69,498.00	-76,075.00	-82,272.00
3,757,507.00	136,985.00	114,585.00	94,226.00	75,662.00	58,683.00	43,108.00	28,783.00	15,572.00	3,358.40	-7,959.50	-18,471.00	-28,255.00	-37,379.00	-45,905.00	-53,886.00	-61,371.00	-68,401.00	-75,015.00	-81,246.00
3,777,077.00	139,190.00	116,672.00	96,205.00	77,541.00	60,471.00	44,813.00	30,411.00	17,129.00	4,849.10	-6,530.30	-17,099.00	-26,936.00	-36,111.00	-44,683.00	-52,709.00	-60,235.00	-67,304.00	-73,954.00	-80,221.00
3,796,647.00	141,394.00	118,758.00	98,183.00	79,421.00	62,260.00	46,519.00	32,039.00	18,686.00	6,339.80	-5,101.10	-15,727.00	-25,618.00	-34,842.00	-43,462.00	-51,531.00	-59,099.00	-66,207.00	-72,894.00	-79,195.00
3,816,218.00	143,599.00	120,844.00	100,161.00	81,300.00	64,049.00	48,224.00	33,667.00	20,242.00	7,830.50	-3,671.90	-14,355.00	-24,299.00	-33,574.00	-42,241.00	-50,354.00	-57,963.00	-65,110.00	-71,834.00	-78,170.00
3,835,788.00	145,804.00	122,931.00	102,140.00	83,180.00	65,838.00	49,929.00	35,296.00	21,799.00	9,321.30	-2,242.70	-12,984.00	-22,981.00	-32,306.00	-41,019.00	-49,177.00	-56,827.00	-64,013.00	-70,774.00	-77,145.00
3,855,358.00	148,008.00	125,017.00	104,118.00	85,059.00	67,627.00	51,635.00	36,924.00	23,356.00	10,812.00	-813.48	-11,612.00	-21,663.00	-31,037.00	-39,798.00	-47,999.00	-55,691.00	-62,916.00	-69,714.00	-76,119.00
3,874,929.00	150,213.00	127,103.00	106,096.00	86,939.00	69,415.00	53,340.00	38,552.00	24,913.00	12,303.00	615.74	-10,240.00	-20,344.00	-29,769.00	-38,576.00	-46,822.00	-54,555.00	-61,819.00	-68,654.00	-75,094.00
3,894,499.00	152,418.00	129,190.00	108,075.00	88,818.00	71,204.00	55,045.00	40,180.00	26,470.00	13,793.00	2,045.00	-8,867.80	-19,026.00	-28,501.00	-37,355.00	-45,644.00	-53,419.00	-60,722.00	-67,594.00	-74,068.00
3,914,069.00	154,622.00	131,276.00	110,053.00	90,698.00	72,993.00	56,750.00	41,808.00	28,027.00	15,284.00	3,474.20	-7,495.90	-17,708.00	-27,232.00	-36,133.00	-44,467.00	-52,283.00	-59,625.00	-66,533.00	-73,043.00
3,933,640.00	156,827.00	133,362.00	112,031.00	92,578.00	74,782.00	58,456.00	43,437.00	29,584.00	16,775.00	4,903.40	-6,124.00	-16,389.00	-25,964.00	-34,912.00	-43,290.00	-51,147.00	-58,528.00	-65,473.00	-72,018.00
3,953,210.00	159,032.00	135,449.00	114,010.00	94,457.00	76,571.00	60,161.00	45,065.00	31,141.00	18,266.00	6,332.60	-4,752.10	-15,071.00	-24,696.00	-33,691.00	-42,112.00	-50,011.00	-57,431.00	-64,413.00	-70,992.00
3,972,780.00	161,236.00	137,535.00	115,988.00	96,337.00	78,359.00	61,866.00	46,693.00	32,698.00	19,756.00	7,761.80	-3,380.20	-13,752.00	-23,427.00	-32,469.00	-40,935.00	-48,875.00	-56,334.00	-63,353.00	-69,967.00
3,992,351.00	163,441.00	139,621.00	117,966.00	98,216.00	80,148.00	63,572.00	48,321.00	34,254.00	21,247.00	9,191.00	-2,008.30	-12,434.00	-22,159.00	-31,248.00	-39,758.00	-47,739.00	-55,237.00	-62,293.00	-68,942.00
4,011,921.00	165,646.00	141,708.00	119,945.00	100,096.00	81,937.00	65,277.00	49,950.00	35,811.00	22,738.00	10,620.00	-636.44	-11,116.00	-20,891.00	-30,026.00	-38,580.00	-46,603.00	-54,140.00	-61,233.00	-67,916.00
4,031,491.00	167,850.00	143,794.00	121,923.00	101,975.00	83,726.00	66,982.00	51,578.00	37,368.00	24,229.00	12,049.00	735.46	-9,797.20	-19,622.00	-28,805.00	-37,403.00	-45,467.00	-53,043.00	-60,173.00	-66,891.00
4,051,062.00	170,055.00	145,880.00	123,901.00	103,855.00	85,515.00	68,688.00	53,206.00	38,925.00	25,719.00	13,479.00	2,107.40	-8,478.80	-18,354.00	-27,584.00	-36,225.00	-44,331.00	-51,947.00	-59,112.00	-65,865.00
4,070,632.00	172,260.00	147,967.00	125,880.00	105,734.00	87,304.00	70,393.00	54,834.00	40,482.00	27,210.00	14,908.00	3,479.30	-7,160.40	-17,086.00	-26,362.00	-35,048.00	-43,195.00	-50,850.00	-58,052.00	-64,840.00
4,090,203.00	174,464.00	150,053.00	127,858.00	107,614.00	89,092.00	72,098.00	56,462.00	42,039.00	28,701.00	16,337.00	4,851.20	-5,842.00	-15,817.00	-25,141.00	-33,871.00	-42,059.00	-49,753.00	-56,992.00	-63,815.00
4,109,773.00	176,669.00	152,139.00	129,836.00	109,493.00	90,881.00	73,803.00	58,091.00	43,596.00	30,191.00	17,766.00	6,223.10	-4,523.60	-14,549.00	-23,919.00	-32,693.00	-40,923.00	-48,656.00	-55,932.00	-62,789.00

Figure 7. Applied Analytics—Scenario Tables

Step 5: Monte Carlo Risk Simulation

Figure 8 illustrates the *Risk Simulation* analysis, where Monte Carlo risk simulations can be set up and run. Analysts can set up probability distribution assumptions on any combination of inputs, run a risk simulation tens to hundreds of thousands of trials, and retrieve the simulated forecast outputs as charts, statistics, probabilities, and confidence intervals to develop comprehensive risk profiles of the projects.

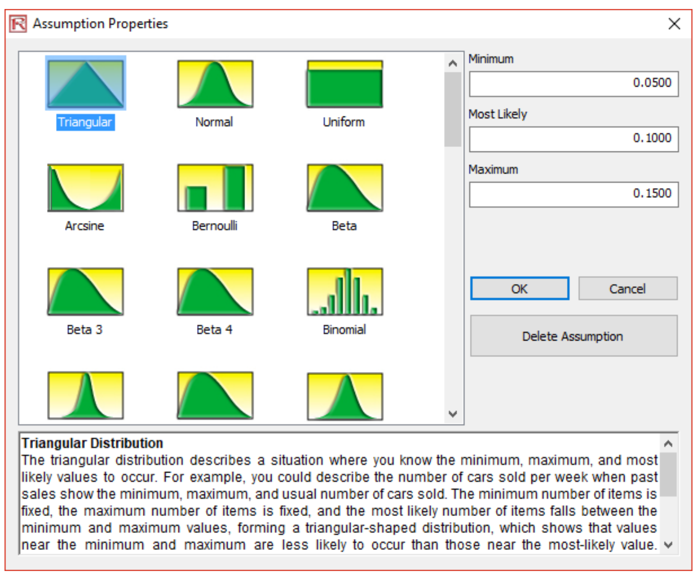


Figure 8. Monte Carlo Risk Simulation Input Assumptions

Simulation Results, Confidence Intervals, and Probabilities

Figure 9 illustrates the *Risk Simulation* results. The simulation forecast chart is shown on the right, while percentiles and simulation statistics are presented on the left.

Statistics/Percentiles	Value
Trials	10,000.00
Mean	1,264,569.20
Median	1,223,025.65
Stdev	323,440.89
CV	0.26
Skew	0.59
Kurtosis	0.07
Minimum	528,515.81
Maximum	2,690,456.43
Range	2,161,940.62
0.00%	528,515.81
5.00%	806,158.76
10.00%	873,477.43
20%	$975,191
30%	1,066,998.73
40.00%	1,146,536
50.00%	1,223,025.65
60.00%	1,310,131.64
70.00%	1,408,675.46
80.00%	152992680.50%
90.00%	1,711,752.31
95.00%	1,871,099.08
100.00%	2,690,456.43

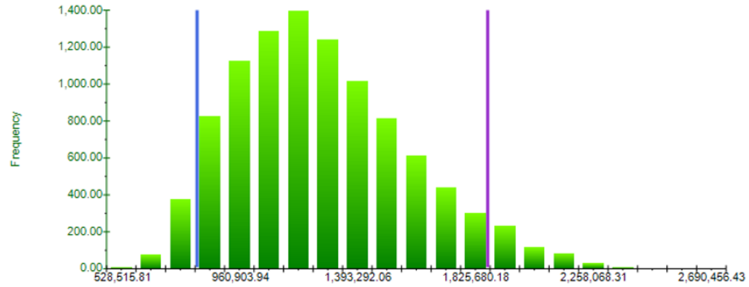


Figure 9. Monte Carlo Risk Simulation Results

Probability Distribution Overlay Charts

Figure 10 illustrates the *Overlay Results*. Multiple simulation output variables can be compared at once using the overlay charts. Analysts simply check/uncheck the simulated outputs they wish to compare and select the chart type to show (e.g., S-Curves, CDF, PDF). Analysts can also add percentile or certainty lines by first selecting the output chart, then entering the relevant values, and finally clicking the *Update* button. The generated charts are highly flexible in that analysts can modify them using the included chart icons (as well as whether to show or hide gridlines), and the chart can be copied into the Microsoft Windows clipboard for pasting into another software application. Typically, S-curves or CDF curves are used in overlay analysis when comparing the risk profile of multiple simulated forecast results.

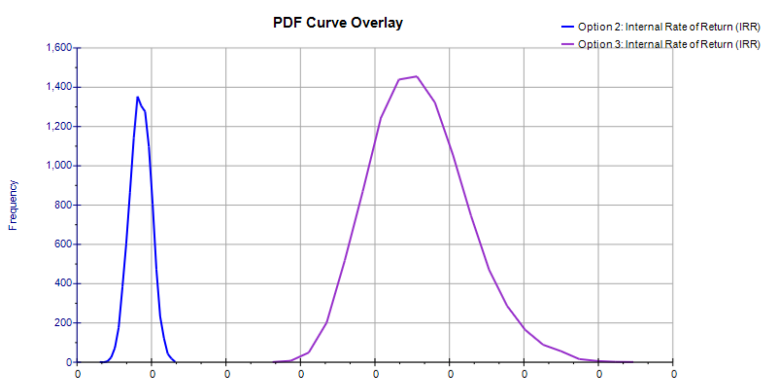


Figure 10. Simulated Overlay Results

Analysis of Alternatives and Dynamic Sensitivity Analysis

Figure 11 illustrates the *Analysis of Alternatives* results. Whereas the *Overlay Results* shows the simulated results as charts (PDF/CDF), the *Analysis of Alternatives* shows the results of the simulation statistics in a table format as well as a chart of the statistics so that one project can be compared against another. The standard approach is to run an analysis of alternatives to compare one project to another, but analysts can also choose to analyze the results on an incremental analysis basis.

OPTIONS	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
Acronym										
Mean	1,264,569.20	-129,548.71	115,517.52	104,069.16	186,548.19	50,886.00	982,026.93	2,222,255.83	120,139.43	115,842.87
Median	1,223,025.65	-269,130.82	111,946.33	101,647.69	182,533.06	48,903.31	809,951.34	2,125,984.32	118,821.08	113,873.98
Stdev	323,440.89	756,980.40	33,246.01	27,242.55	42,751.66	24,260.40	1,841,083.18	774,387.88	22,748.49	26,884.24
CV	25.58%	584.32%	28.78%	26.18%	22.92%	47.68%	187.48%	34.85%	18.94%	23.21%
Skew	0.59	0.83	0.50	0.46	0.46	0.41	0.48	0.64	0.31	0.38
Kurtosis	0.07	0.42	-0.06	-0.02	-0.05	-0.06	0.18	0.29	-0.06	-0.02
Minimum	528,515.81	-1,612,389.19	33,915.58	34,781.88	72,360.45	-13,544.30	-4,062,019.59	409,940.95	53,294.46	45,687.22
Maximum	2,690,456.43	3,186,736.54	238,613.77	208,832.14	361,534.33	150,216.66	8,105,902.62	5,492,144.74	213,754.98	234,987.45
Range	2,161,940.62	4,799,125.72	204,698.19	174,050.27	289,173.87	163,760.96	12,167,922.22	5,082,203.79	160,460.52	189,300.23
0% Percentile	528,515.81	-1,612,389.19	33,915.58	34,781.88	72,360.45	-13,544.30	-4,062,019.59	409,940.95	53,294.46	45,687.22
5% Percentile	806,158.76	-1,126,810.37	66,833.21	63,341.55	123,647.00	14,407.25	-1,721,563.12	1,118,422.25	85,021.02	74,880.17
10% Percentile	873,477.43	-985,321.30	75,292.44	70,536.07	134,523.19	21,061.66	-1,234,281.88	1,308,170.97	91,480.18	82,478.56
20% Percentile	975,191.16	-787,408.29	86,592.52	80,551.23	149,044.20	29,596.95	-575,471.45	1,553,575.46	100,319.83	92,352.05
30% Percentile	1,066,998.73	-607,802.26	95,258.85	87,689.17	160,430.73	36,309.09	-88,078.13	1,756,505.72	107,072.89	100,314.71
40% Percentile	1,146,536.48	-435,048.39	103,478.90	94,871.67	171,896.55	42,716.18	366,415.18	1,937,629.66	113,197.08	106,958.95
50% Percentile	1,223,025.65	-269,130.82	111,946.33	101,647.69	182,533.06	48,903.31	809,951.34	2,125,984.32	118,821.08	113,873.98
60% Percentile	1,310,131.64	-70,640.29	120,924.23	108,733.13	193,556.04	55,280.95	1,260,274.23	2,321,587.17	124,955.05	121,112.91
70% Percentile	1,408,675.46	168,159.10	130,549.63	116,448.61	206,334.42	62,431.52	1,795,294.68	2,549,885.15	131,348.03	128,934.06
80% Percentile	1,529,926.80	474,006.49	143,040.93	127,054.19	222,193.22	71,595.89	2,464,689.40	2,848,749.31	139,239.82	138,456.24
90% Percentile	1,711,752.31	956,928.86	161,722.53	141,005.97	245,083.83	83,760.91	3,475,890.85	3,275,508.70	150,031.84	151,426.79
95% Percentile	1,871,099.08	1,333,426.70	177,165.94	153,294.40	263,658.89	93,827.83	4,368,679.78	3,668,268.40	159,781.91	163,466.89
100% Percentile	2,690,456.43	3,186,736.54	238,613.77	208,832.14	361,534.33	150,216.66	8,105,902.62	5,492,144.74	213,754.98	234,987.45

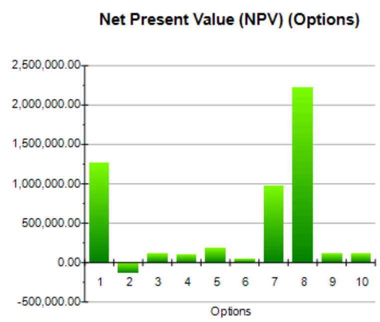


Figure 11. Simulated Analysis of Alternatives

Step 6: Strategic Real Options Valuation Modeling

Figure 12 illustrates the *Options Strategies* tab. *Options Strategies* is where analysts can draw their own custom strategic maps, and each map can have multiple strategic real options paths. This analysis allows analysts to draw and visualize these strategic pathways and does not perform any computations. The examples in Figures 1 and 2 can be easily incorporated into the strategy tree seen in Figure 12.

Real Options Valuation Modeling

Figure 13 illustrates the *Options Valuation* and the *Strategy View*. This part of the analysis performs the calculations of real options valuation models. Analysts must understand the basic concepts of real options before proceeding. This analysis internalizes the more sophisticated Real Options SLS software (see Chapter 13 of Mun's *Modeling Risk* book [Mun, 2015]). Instead of requiring more advanced knowledge of real options analysis and modeling, analysts can simply choose the real option types, and the required inputs will be displayed for entry. Analysts can compute and obtain the real options value quickly and efficiently, as well as run the subsequent tornado, sensitivity, and scenario analyses.

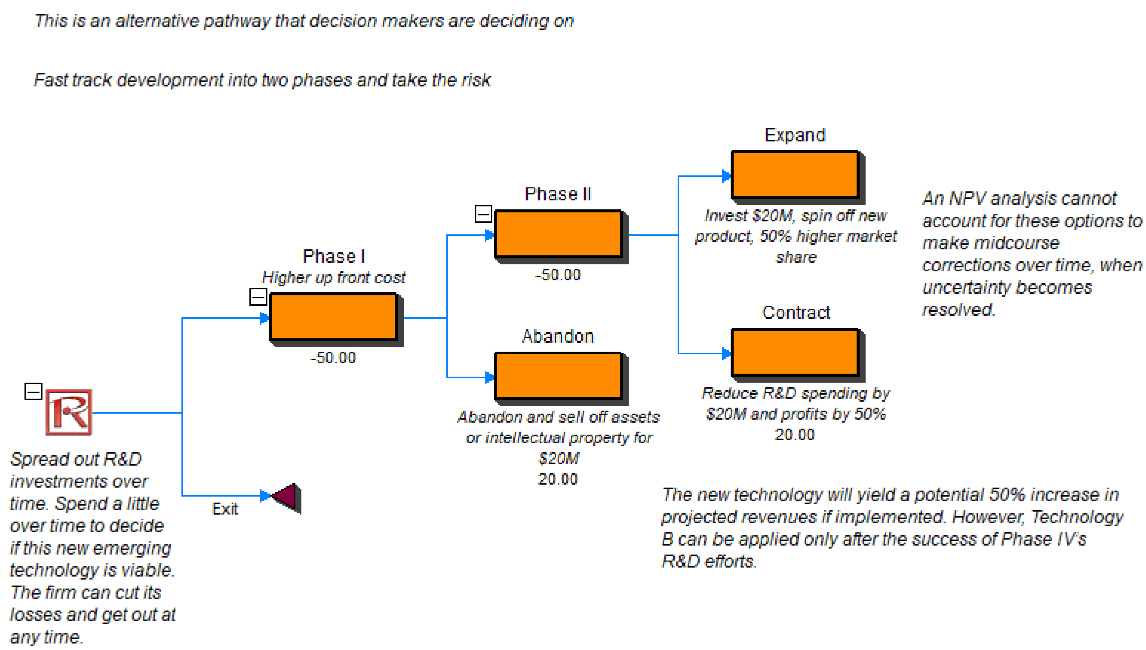


Figure 12. Framing Flexibility and Options Strategies

American: Option to Abandon	450,355.44		Result:
Asset Value (Present Value of Net Benefits):	445,625.18		450,355.44
Volatility (Annualized Risk %):	0.22		
Maturity (Total Years to Option Expiration):	5.00		
Risk-Free Rate (Riskless Discount Rate %):	0.04		
Dividend Rate (Opportunity Cost %):	0.00		
Lattice Steps (Typically 100 to 1000):	100.00		
Salvage:	250,000.00		

Figure 13. Value of Flexibility Options

The strategic real options analysis is solved by employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using modified closed-form sequential compound option models. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. This subsection is meant as a quick peek into the math underlying a very basic closed-form compound option. It is only a preview of the detailed modeling techniques used in the current analysis and should not be assumed to be the final word. For instance, as suggested in Mun (2016), we first start by solving for the critical value of *I,* an iterative component in the model, using the following equation:

$$X_2 = Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$
$$-X_1 e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$

Then, solve recursively for the value from the previous equation and input it into the model:

$$
\begin{aligned}
Compound\ Option = {} & Se^{-qT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}};\sqrt{t_1/T_2}\end{array}\right] \\
& - X_1e^{-rT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}-\sigma\sqrt{T_2};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1};\sqrt{t_1/T_2}\end{array}\right] \\
& - X_2e^{-rt_1}\Phi\left[\dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1}\right]
\end{aligned}
$$

Additional methods using closed-form solutions, binomial and trinomial lattices, and simulation approaches, as well as dynamic simulated decision trees are used in computing the relevant option values of each strategic pathway as previously indicated.

Step 7: Portfolio Optimization

In today's competitive global economy, companies are faced with many difficult decisions. These decisions include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical and maybe even impossible.

A model can provide valuable assistance in incorporating relevant variables when analyzing decisions and in finding the best solutions for making decisions. Models capture the most important features of a problem and present them in a form that is easy to interpret. Models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., which products to sell or which projects to execute) in every conceivable way such that the objective is maximized (e.g., revenues and net income) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., budget and resources).

The projects can be modeled within the ROV software as a portfolio and optimized to determine the best combination of projects for the portfolio in the *Optimization Settings* subtab. Analysts start by selecting the optimization method (Static or Dynamic Optimization). Then they select the decision variable type of *Discrete Binary* (choose which Project or Options to execute with a Go/No-Go Binary 1/0 decision) or *Continuous Budget Allocation* (returns % of budget to allocate to each *option* or *project* as long as the total portfolio is 100%); select the *Objective* (Max NPV, Min Risk, etc.); set up any *Constraints* (e.g., budget restrictions, number of projects restrictions, or create customized restrictions); select the options or projects to optimize/allocate/choose (default selection is *all options*); and when completed, run the Optimization.

Figure 15 illustrates the *Optimization Results*, which returns the results from the portfolio optimization analysis. The main results are provided in the data grid, showing the final *Objective Function* results, final *Optimized Constraints*, and the allocation, selection, or optimization across all individual options or projects within this optimized portfolio. The top portion of the figure shows the textual details and results of the optimization algorithms applied, and the chart illustrates the final objective function. The chart will only show a single point for regular optimizations, whereas it will return an investment efficient frontier curve if the optional *Efficient Frontier* settings are set (min, max, step size). Figures 15 and 16 provide examples of the critical results for decision-makers as they allow flexibility in designing their own portfolio of options. For instance, Figure 15 shows an efficient frontier of portfolios, where each of the points along the curve represents an optimized portfolio subject to a certain set of constraints. In this example, the constraints were the number of options that can be selected in a ship, and the total cost of obtaining these options is subject to a budget constraint. The colored columns on the right in Figure 15 show the various combinations of budget limits and maximum number of options allowed. For instance, if a program office in the Navy allocates only $2.5 million (see the Frontier Variable located on the second row) and no more than four options per ship, then only options 3, 7, 9, and 10 are feasible, and this portfolio combination would generate the biggest bang for the buck while simultaneously satisfying the budgetary and number of options constraints. If the constraints were relaxed to, say, five options and a $3.5 million budget, then option 5 is added to the mix. Finally, at $4.5 million and no more than seven options per ship, options 1 and 2 should be added to the mix. Interestingly, even with a higher budget of $5.5 million, the same portfolio of options is selected. In fact, the Optimized Constraint 2 shows that only $4.1 million is used. Therefore, as a decision-making tool for the budget-setting officials, the maximum budget that should be set for this portfolio of options should be $4.1 million. Similarly, the decision-maker can move backwards, where, say, if the original budget of $4.5 million were slashed by the U.S. Congress to $3.5 million, then the options that should be eliminated are options 1 and 2.

While Figure 15 shows the efficient frontier where the constraints such as number of options allowed and budget were varied to determine the efficient portfolio selection, Figure 16 shows multiple portfolios with different objectives. For instance, the five models shown were to maximize the financial bang for the buck (minimizing cost and maximizing value while simultaneously minimizing risk), maximizing OPNAV value, maximizing KVA value, maximizing Command value, and maximizing a Weighted Average of all objectives. This capability is important because analysts' objectives and decisions will differ based on different perspectives. Using a multiple criteria optimization approach allows us to see the scoring from all perspectives. Options with the highest count (e.g., 5) would receive the highest priority in the final portfolio, as it satisfies all stakeholders' perspectives, and would, hence, be considered first, followed by options with counts of 4, 3, 2, and 1.

Conclusions and Recommendations

Strategic real options valuation (ROV) provides the decision-maker the right, but not the obligation, to hold off on executing a certain decision until a later time when uncertainties are resolved and when better information is available. The option implies that flexibility to execute a certain path exists and was predetermined or predesigned in advance. Based on the research performed thus far, we conclude that the methodology has significant merits and is worthy of more detailed follow-on analysis. It is therefore recommended that the ROV methodology be applied on a real case facing the Navy with actual data, and the project's outcomes tracked over time.

Objective Function	6.1286	6.7465	6.9478	6.9478	6.9478
Frontier Variable	2000000.0000	2500000.0000	3000000.0000	3500000.0000	4000000.0000
Optimized Constraint	1978818.0000	2487042.0000	2718646.0000	2718646.0000	2718646.0000
Option1	1.00	1.00	1.00	1.00	1.00
Option2	0.00	1.00	1.00	1.00	1.00
Option3	1.00	1.00	1.00	1.00	1.00
Option4	1.00	1.00	1.00	1.00	1.00
Option5	1.00	0.00	1.00	1.00	1.00
Option6	0.00	0.00	1.00	1.00	1.00
Option7	0.00	0.00	0.00	0.00	0.00
Option8	1.00	1.00	1.00	1.00	1.00
Option9	0.00	0.00	1.00	1.00	1.00
Option10	0.00	1.00	1.00	1.00	1.00

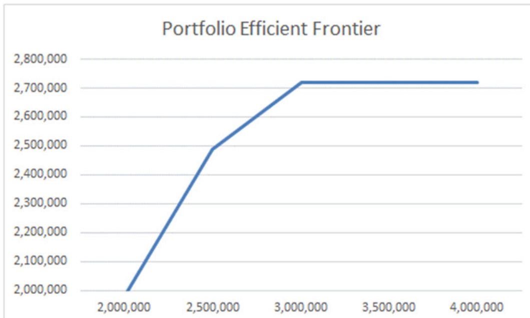


Figure 14. Portfolio Optimization Results

Model	Model 1	Model 2	Model 3	Model 4	Model 5	Count
Objective	1,408,735.73	51.16	53.56	48.10	53.56	
Budget Constraint	3,800,000	4,000,000	4,000,000	3,750,000	4,000,000	
Program Constraint	6	7	7	6	7	
Option 1	1.00	1.00	1.00	0.00	1.00	4
Option 2	0.00	0.00	0.00	0.00	0.00	0
Option 3	1.00	1.00	1.00	1.00	1.00	5
Option 4	0.00	1.00	1.00	0.00	1.00	3
Option 5	1.00	1.00	1.00	1.00	1.00	5
Option 6	0.00	1.00	1.00	1.00	1.00	4
Option 7	1.00	0.00	0.00	0.00	0.00	1
Option 8	0.00	1.00	1.00	1.00	1.00	4
Option 9	1.00	0.00	0.00	1.00	0.00	2
Option 10	1.00	1.00	1.00	1.00	1.00	5

Figure 15. Multi-Criteria Portfolio Optimization Results

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